Designing, testing and validating a COTS pigtailed analog output InGaAs APD receiver for rugged defense applications

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Introduction

Laser range finding (LRF) and LiDAR for defense have requirements that are different from those made for commercial applications:

- Detection of short pulses of low and high power light
- Ability to operate in harsh environments and over a wide temperature range
- Large dynamic range
- Fast overload recovery to detect subsequent signals after sensing bright targets
- Withstand high optical power density, improving damage threshold to the detector

In addition to these criteria, many LRF and LiDAR system designs would benefit from having optical fibers in both transmission and receiving as ways to improve system thermal management and reducing overall system noise(1). Commercial off the shelf (COTS) components are desired for many defense applications, as the COTS are more readily available and more cost effective. CMC is introducing a new family of COTS pigtailed SMT package Indium Gallium Arsenide (InGaAs) avalanche photodiode (APD) LIDAR/LRF receivers, 276-339832-VAR, designed, tested and validated against MIL-STD specs. This COTS APD receiver offer the performance that enables detection of longer range of smaller targets more accurately. The robust fiber pigtail package supports space saving and easier system integration, while meeting MIL-STD environmental operating conditions.

Electrical design characteristics

To meet the simultaneous demand of detecting and withstanding short pulses of high power laser signal, maintaining high dynamic range, having the ability to recover quickly from optical signal overload and functional well in demanding conditions, there are several important design criteria to consider.

Firstly, having low excess noise factor APD lowers the noise floor of the receiver as a whole, when compare with similar transimpedence amplifier (TIA) circuit designs. Many experimental designs have been explored on impact ionization theories (2, 3). Although smaller active area APDs will yield lower noise, higher bandwidth and dynamic range, the trade-off becomes the challenge of optical fiber coupling or other optical alignment methods. The first variant of this COTS family of fiber coupled InGaAs APD receiver is based on a 50um core multi-mode (MM) fiber. Work is continuing on a 200um core MM fiber device. In addition to having the advantage of low excess noise factor, the APD chosen by CMC has been optimized for fast optical overload recovery.

The second consideration is given to the receiver's TIA design. For most long-range laser range finders and scanning LiDAR, the returning optical signals from targets can range from low levels of nanowatts (nW) to high levels of milliwatts (mW) [4]. Further away small targets' low return signal requires a detector with high sensitivity whereas close and high reflective targets' high return optical power can easily saturate or damage the photo receiver. Thus, an APD receiver with the lowest noise equivalent power (NEP) for a given bandwidth would offer the best signal to noise performance. For the equipment to function effectively and accurately, the optical receiver must have the high dynamic range capability to detect both extreme signal levels.

Typical APD-TIA receivers will saturate easily with peak optical powers in less than 10µW. The solution to compensate this shortcoming with reducing the transimpedence of the receiver would lead to low sensitivity, which renders the detector useless to detect low signals. The solution is to implement a dual transimpedence circuit with auto-switching function, which protects the receiver from saturation at the same time keeping the high dynamic range and sensitivity.

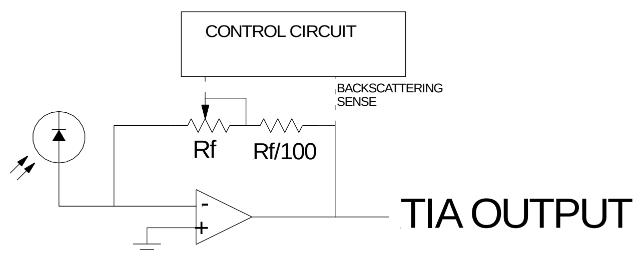

Figure 1 - Continuous auto switching circuit

After encountering high return optical signals, the receiver must be able to recover quickly in order to detect subsequent signals without delay, or risk rendering the equipment ineffective. Hence the next consideration of the TIA is overload recovery speed while maintaining the sensitivity and dynamic range of the APD receiver.

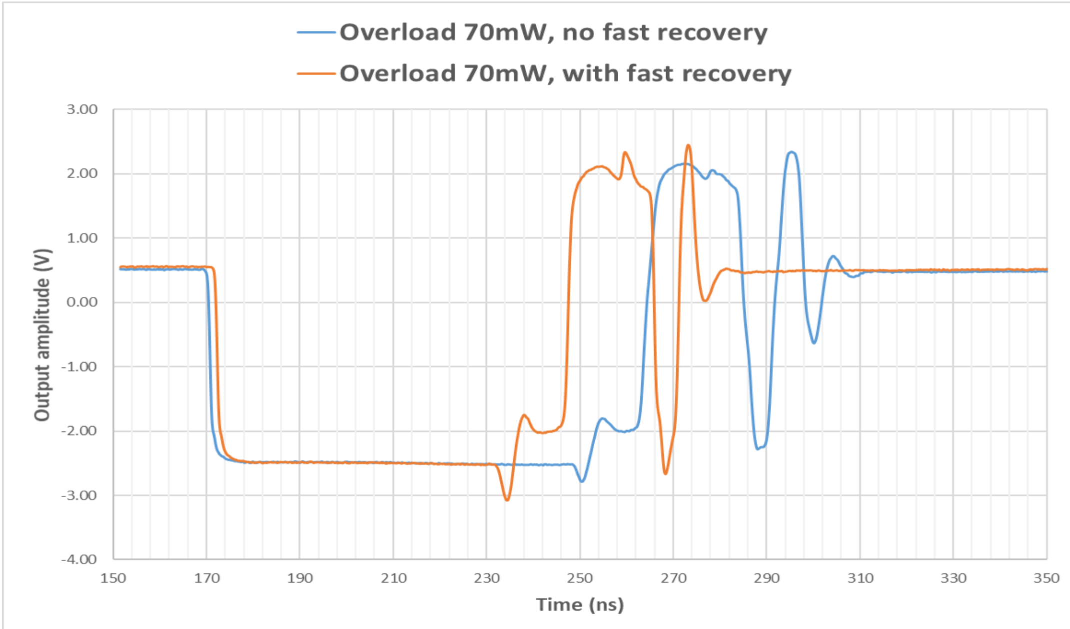

Figure 2: Fast recovery circuit reduces the recovery time by 20-25ns (14%)

The CMC proprietary overload recovery design demonstrated that no sacrifice of noise performance at ambient temperature, while maintaining the capability to sustain and recover from high optical power overload.

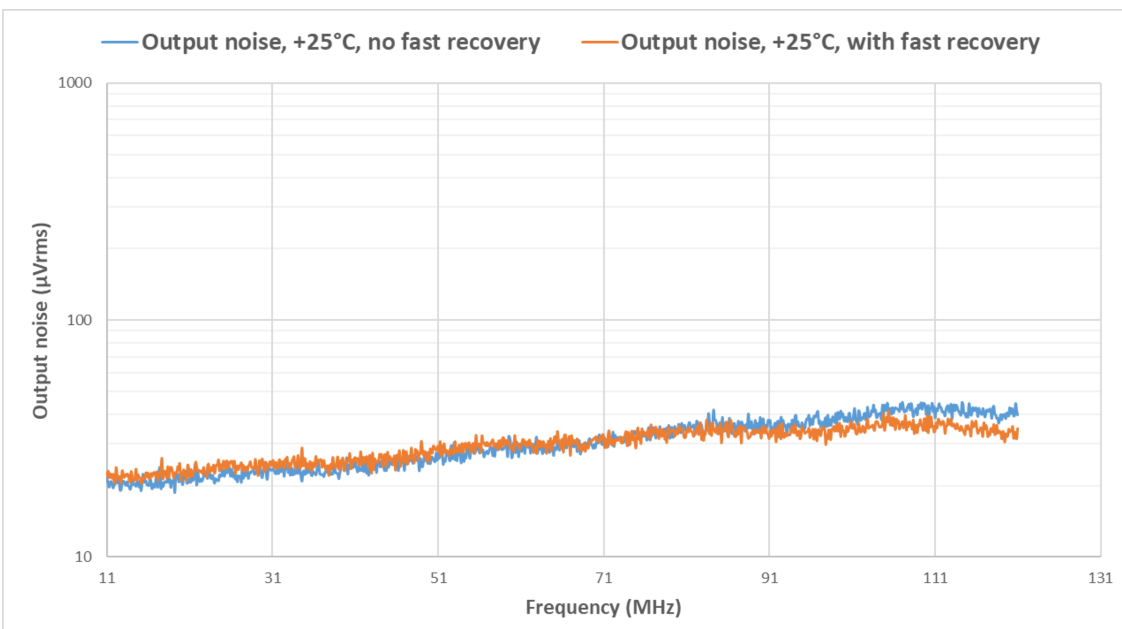

Figure 3: APD receiver output noise at ambient temperature, with and without fast overload recovery

In addition, there is also insignificant change in rise and fall time for the receiver.

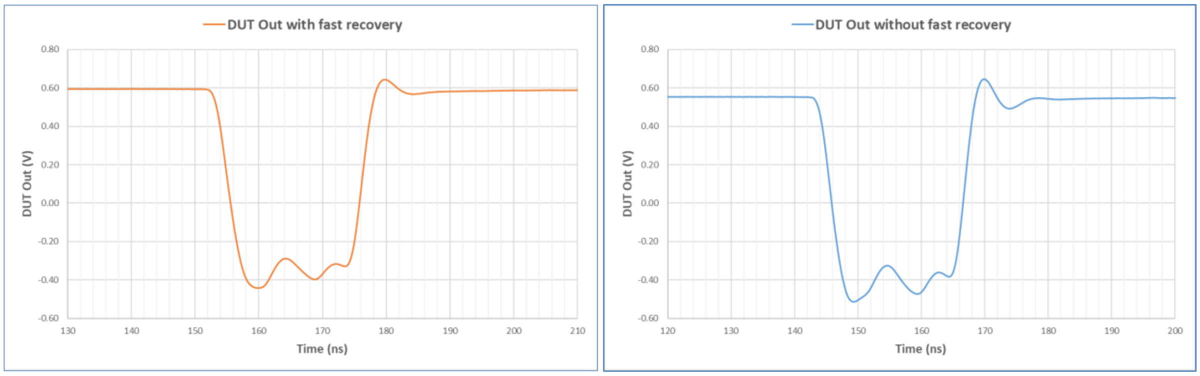

Figure 4. 1V output swing in linear mode, showing rise/fall time of 3.2ns and 2.8ns for receiver with and without fast overload recovery circuits.

To detect the low signal, the APD receiver's noise must be kept lowest possible. The receiver's total noise comes from the APD and the amplifier. By selecting the low impact ionization APD and a custom design discrete TIA, the thermal noise from the feedback resistance, shot noise from any leakage current, noise current and noise voltage from commercial available TIAs are significantly reduced or eliminated[5].

While maintaining all of the existing CMC TO through-hole family of receivers' bandwidth, APD gain, CMC's new pigtailed surface mount (SMT) receiver can achieve NEP as low as 200 fW/√Hz at +85°C. This fiber pigtailed receiver also shows higher responsivity and lower NEP when compared to other COTS TO through-hole receivers of similar bandwidth.

Supplier	P/N	BW (MHz)	NEP (pW/√Hz)	NEP Integrated up to BW	Resp (kV/W)	Op Temp (°C)
CMC Electronics	264-339832-001	120	0.09	1-121 MHz	580	-40 to +85
CMC Electronics	264-339822-001	100	0.11	1-50 MHz	580	-40 to +85
CS Rayzer optical Tech	CR200AH-1550-100M	100	0.12	100 kHz ± 1 Hz	400	-40 to +85
Excelitas technologies	C30659-1550-R08BH	200	0.22	100 kHz ± 1 Hz	90	-40 to +85
Laser Components	IAG200H2	100	0.25	100 kHz ± 1 Hz	500	-40 to +85

Table 1: Comparison of CMC's fiber pigtailed 264-339832 receiver vs. similar InGaAs APD receiver in TO through-hole package performance at ambient temperature (25°C)

Mechanical design characteristics

There are advantages of a fiber pigtail package optical receiver in many applications. It is commonly known that stray light or other types of electro-magnetic interference (EMI) can adversely affect overall electro and optical system performance[6, 7 8]. APD receiver, being the critical component in LRF and LiDAR applications, should have designs that minimize EMI susceptibility. Many of the TIA parts are silicon semiconductors, so the circuit performance can be compromised with light interference. Compared to non-fibered receivers such as traditional TO packages, a light tight package with fiber aligned directly and closely to the APD active area enables the capture of essentially all optical signals. Such package solution ensures that the electronic components are shielded from stray light and increases the operating input power range of the CMC APD-TIA receiver by a factor from 10x to 30x.

Package configuration	Max input power (W) 1064nm, 20ns pulses
Free-space, no light shield	4
Free-space, with light shield on active components	125

Table 2: Difference in input power for normal receiver performance

Additionally, with a fiber pigtail feeding the optical signal do the APD, the receiver can be placed away from areas of the board that may generate other types of EMI and be less exposed to electromagnetic sources external to the system.

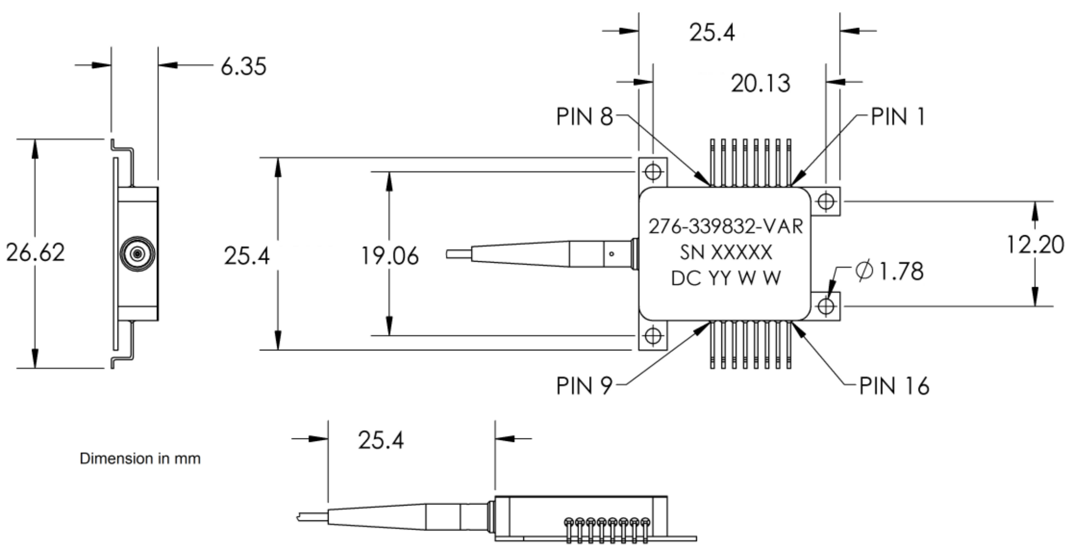

Figure 4: Compact, hermetic, light tight fiber pigtailed package

Both the InGaAs APD chip and TIA electronic circuitry are susceptible to moisture effects. To support rugged defense and security applications, hermeticity of active optoelectronic component such as an APD receiver is crucial as this affects reliability of the system. A hermetic package is designed to prevent moisture from entering the package. Generally epoxy fiber pigtail attachment to optical detector packages have high risk of moisture leakage, which over time would lead to performance degradation and device failure [9].

For any fiber pigtailed APD receiver, the challenge is how the fiber is fixed to the package housing the APD and TIA electronics.   There are two types of fiber attachment that would meet hermeticity requirements: solder with metalized fiber or glass seal with electro induction preform onto the ferrule or feedthrough of the device package.

All fiber attachment processes need to consider similar key issues: melting temperature of either the solder or glass preform for attachment, compatibility of the coefficients of thermal expansion of the package and the fiber attaching medium, the amount of time required to melt and flow the medium, and the design of the ferrule on supporting the fiber's tensile strength[10]. Upon overcoming these design challenges, the process also has to be reproducible easily and consistently.

The CMC 264-339832 series of fiber pigtailed APD receivers uses the electro-induction method of glass preform to fix the fiber pigtail onto the Kovar butterfly SMT package. This process offers advantages in manufacturing handling, and eliminates the risk of outgassing from solder flux.

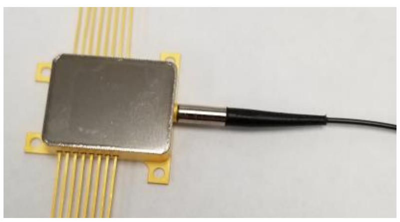

Figure 5: Compact, hermetic, light tight fiber pigtailed package

<u>Testing & Validating to MIL-STD-883 environmental conditions</u>

Offered as a commercial-off-the-shelf (COTS) part, the CMC 264-339832 series of pigtailed InGaAs APD receivers is designed to meet MIL-PRF-38534 class "H" requirements.   Many environmental tests such as temperature cycling, constant acceleration, gross and fine leak tests, vibration, die shear and wire bond strength, among others are the basis for validating the device performance as part of the design process.

Test	Military specification	Test conditions
Hermeticity	MIL-STD-883 test method 1014.13	Optical leak test Leak ≤ 1 X 10^{-6} atm cc/sec Air
Temperature cycling	MIL-STD-883 test method 1010	10 cycles, -55°C to +85°C
Constant acceleration	MIL-STD-883 test method 2001	Tested at 2000g Plan to design for 5000g
Random vibration	MIL-STD-883 test method 2026	Test planned for next quarter

Table 3. MIL-STD tests for validating 264-339832-001 design

Many of these MIL-STD tests were conducted as part of design validation, whereas temperature cycling is a standard screening test for all production units. Customization of individual qualification requirements are available to support defense/military or rugged industrial applications.

The three most critical performance parameters for the APD receiver, the bandwidth, NEP and responsivity, were measured at temperatures of -40, +25 and +85°C after performing the validation tests. The APD receiver has shown to maintain its performance within the expected range.

Temp (°C)	**With fast recovery**		**Without fast recovery**	
	BW (MHz)	**NEP (fW/√Hz)**	**BW (MHz)**	**NEP (fW/√Hz)**
+25	128	84	150	79
-40	142	68	165	67
+85	124	196	145	101

Table 4. Summary performance table across the operating temperature range, with responsivity set at 580kV/W

Conclusion

Many optical ranging and sensing applications would benefit from having a high sensitivity detector with a fiber optic package, for the ease of system integration and performance optimization. The new addition to the CMC family of analogue InGaAs APD receivers, the COTS fiber pigtail package 264-339832 series, has taken the MIL-PRF-38534 design requirements as the foundation. MIL-STD tests conducted have validated this COTS part in meeting the stringent environmental operating conditions while maintaining low NEP, high bandwidth and high responsivity.

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